

Review

Utilising coastal blue carbon (CBC) to mitigate the climate crisis: Current status and future analysis of China

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ABSTRACT

Climate change, driven by greenhouse gas emissions, poses a significant threat to life and livelihoods globally. China, the world's largest carbon emitter, yet has a significant area of coastal blue carbon (CBC) ecosystems covering mangroves, salt marshes, and seagrass beds which are vital for carbon sequestration. This study assesses the current state of these ecosystems, evaluates Chinese policies for CBC conservation, appraise Chinese blue carbon (BC) market development and compares them with international efforts. The findings highlight inadequate conservation measures and a lack of specific laws and enforcement for BC protection in China. The BC market suffers from unclear responsibilities, dampening corporate participation. Recommendations include hastening legal frameworks, bolstering enforcement, defining BC rights and ownership, and involving the public in BC initiatives. A SWOT analysis underscores the need for urgent action to bolster China's CBC ecosystems and market development. (139 words)

1. Introduction

During the carbon sequestration process, based on the carbon-sequestering organisms and their respective environments, it can be broadly categorised into blue carbon (BC) and green carbon (Fig. S1). As the name suggested, BC specifically refers to the organic carbon sequestered by marine and coastal organisms. Marine and coastal ecosystems contributed a lot to the carbon sequestration, whilst the BC accounted for a substantial 55 % of the total biological carbon sequestration (Tang et al., 2018; Nellemann et al., 2009). BC can be divided into coastal blue carbon (CBC) and ocean blue carbon, and as the name suggests, CBC, comprised of mangrove, seagrass and salt marsh ecosystems, primarily focuses on coastal areas and is a significant component of BC (Tang et al., 2018). According to Lovelock and Duarte (2019), CBC ecosystems, utilising only 0.2 % of the ocean surface area, contribute 50 % of organic carbon burial.

In response to climate change, the Chinese government has made commitments, aiming to peak carbon dioxide emissions before 2030 and striving for carbon neutrality by 2060 (The State Council Information Office of the People's Republic of China, 2021). In October 2021, the Central Committee of the Communist Party of China and the State Council issued the "Opinions on Thoroughly Implementing the New

Development Philosophy and Effectively Achieving Carbon Peaking and Carbon Neutrality" and the "Action Plan for Carbon Dioxide Peaking Before 2030" (The State Council of the People's Republic of China, 2021; Department of Resource Conservation and Environmental Protection, 2021). These documents clearly outline China's plans and goals for carbon neutrality. For example, the 14th Five-year Plan and the Outline of the Vision for 2035 stated that, in order to actively address climate change, energy resources should be allocated reasonably, efficiency should be improved, as well as energy consumption and CO₂ emissions per unit of GDP should be reduced by 13.5 % and 18 %, respectively (Xinhua News Agency, 2021). Besides, these documents also indirectly demonstrating China's confidence and commitment to achieve these goals.

China possesses an extensive coastline, with approximately 18,000 km along the mainland and including 7600 islands (Wu et al., 2020; The State Council of the People's Republic of China, 2023; The State Council of the People's Republic of China, n.d.). Along this coastline, BC habitats, including mangroves, seagrasses, salt marsh ecosystems, and seaweed cultivation fields, cover over 3000 square kilometres (Li and Miao, 2022; Xiang et al., 2022). Therefore, China has ample conditions to utilise BC to facilitate carbon neutrality. Additionally, actively protecting BC ecosystems can improve the ecological environment and

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enhance regional climate resilience, helping to prevent or reduce losses caused by natural disasters. Besides, just as with the development of the global green finance market in the past, the current society needs blue finance instruments to guide capital toward blue industries and blue carbon projects. By developing the BC market, it is believed that it can promote employment and drive economic growth. Investing in BC ecosystems through international capital, government funding, and corporate support fosters global collaboration. This not only strengthens the United Nations Sustainable Development Goals (SDGs) and carbon neutrality efforts but also enhances ecological and economic benefits worldwide.

However, over the past 60 years, wetlands have faced increasing threats and pressures due to population growth and rapid economic development (Sun et al., 2015; Xiang et al., 2022). From 1950 to 2014, China lost 8.01×10^6 ha of coastal wetlands, with a total loss rate of 58 %, and approximately 69 % of mangroves were lost due to land reclamation (Sun et al., 2015; Wu et al., 2020).

Based on the existing problem statement and issues, how China can fully utilise its existing BC resources to develop the economy and contribute to carbon neutrality remains a significant challenge. Without proper studies, the abundant BC resources may become less useful to the global community and could even be destroyed if adequate protection measures are not implemented.

This study analysed the current status of China's major CBC ecosystems, including mangroves, salt marshes, and seagrasses ecosystems, in hopes of providing insights into carbon neutrality. Furthermore, by assessing China's relevant BC policies, this study offers a comparative analysis to guide the government's future development directions. Lastly, the study presents examples of CBC market products in China and conducts a SWOT analysis of the BC market, aiming to promote the development of China's BC market. This study integrates the ecosystem,

financial, and political perspectives of BC in China into a single article, thereby providing more solid, practical, and comprehensive recommendations compared to general single-perspective studies. Through this study, it is expected that China will be able to fully utilise its substantial BC resources to address climate change and set a positive example for the global community.

2. Analysis of the current status of China's coastal ecosystems

2.1. Mangrove ecosystem

The area of mangrove forests in China has undergone significant changes throughout its historical dynamics. From the mid-to the end of the 20th century, the mangrove area in China experienced a sharp decline, with substantial regions being converted into agricultural land and utilised for construction and development (Fu et al., 2021; Jia et al., 2021; China Natural Resources News, 2020). In the early 21st century, there was an increased focus on conserving mangrove resources, and the Chinese government began implementing measures whereby the mangrove areas gradually increased (Fu et al., 2021; Huang et al., 2023). The most pessimistic data revealed that the mangrove area in China was only half of its pre-disturbance level in 2022 (Fig. 1) (Huang et al., 2023; Jia et al., 2021). Furthermore, even in the 21st century, while there is current attention and emphasis on managing and protecting mangroves in China, scattered patches of mangroves still face destruction due to weak legal awareness and greed for money (Jia et al., 2021). For instance, a total of 1882.24 ha of mangroves in Chengmai County, Hainan Province, have been utilised for real estate development, leading to the destruction of approximately 6300 mangrove trees (Ministry of Ecology and Environment of the People's Republic of China, 2019). Besides, the carbon sequestration ability of mangrove in China is

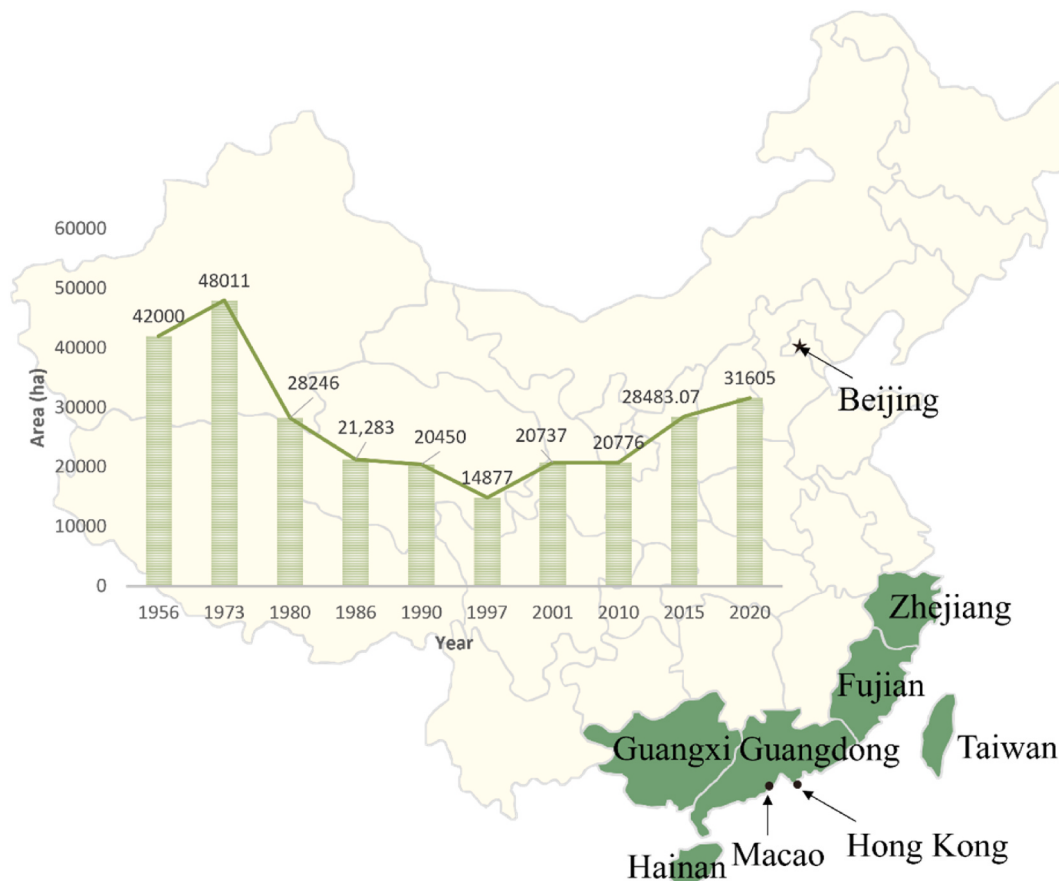


Fig. 1. The primary distribution and year-by-year occupation area of mangroves in China. Adapted from Jia et al. (2021), Fu et al. (2021) and Zhang et al. (2021).

relatively low (Table S1).

2.2. Salt marsh ecosystem

The salt marsh ecosystem is widely distributed in the coastal areas of China, ranging from Liaoning in the north to Guangxi in the south (Chen et al., 2022a; Gu et al., 2018).

The salt marsh ecosystem has sharply declined from 1985 to 2015, followed by a slight recovery in 2019 (Fig. 2) (Chen et al., 2022a; Gu et al., 2018). Despite taking emergency protection measures, such as establishing conservation areas, delineating marine ecological redlines, and implementing strict regulation of reclamation, the area of salt marshes in China has yet to fully recover to the highest level in the late 19th century, with approximately 157,776 ha of maximum area (Ministry of Natural Resources of the People's Republic of China, 2021; Gu et al., 2018).

In the past, land reclamation was the primary factor leading to significant loss of salt marshes (Dong et al., 2023; Gu et al., 2018). At present, stricter criteria for land reclamation have been established, resulting in a noticeable reduction in reclamation projects. For instance, "The Measures for the Protection and Utilization of Coastlines" released in 2017, explicitly stipulates that the Chinese nationwide natural coastline retention rate should not be less than 35 % by 2020 (State Oceanic Administration, 2017). However, the existing documents do not impose legal prohibitions or restrictions, and the substantial profits associated with converting coastal wetlands into arable land or construction sites make it challenging to eradicate activities that harm salt marsh ecosystems in China (Feng and Liao, 2023; Lei et al., 2017).

In light of this, the Chinese government may consider formulating relevant protective legislation to ensure that law enforcement agencies have a legal foundation, are obligated to follow the law, enforce it

rigorously, and hold violators accountable. As a result, progressive efforts should be made to prevent land reclamation and the transformation of wetlands into residential areas in China.

2.3. Seagrass ecosystem

The seagrass ecosystem in China is widely distributed (Fig. 3), with two main distribution areas, namely the Yellow Sea-Bohai Sea distribution areas in the northern China and South China Sea in southern China (Li et al., 2022a; Xiao et al., 2020; Zhou et al., 2023).

The seagrass ecosystem provides crucial ecosystem services but is among the least protected marine ecosystems in China (Hu et al., 2021; Herr et al., 2016). Having started seagrass research relatively late, China needs more historical statistical information on seagrasses (Jiang et al., 2017; Zhou et al., 2023; Zheng et al., 2013).

Due to numerous influencing factors, China's seagrass habitats have been degrading with their extent rapidly diminishing and dispersing over the past few decades (Hu et al., 2021; Huang et al., 2024; Pan et al., 2011; Zheng et al., 2013).

Under the decreasing circumstances, it is advised for the Chinese government to conduct comprehensive assessments of the seagrass ecosystem to gain a clearer understanding of their current status, which includes specific area measurement, species distribution and unique challenges faced by each region. Based on the information above, more attention shall be placed on the protection of seagrass ecosystem to effectively increase the BC sink.

2.4. Brief summary on China's current CBC ecosystem

From the historical perspective, all three CBC (mangrove, salt marsh and seagrass) ecosystems in China have been damaged due to the

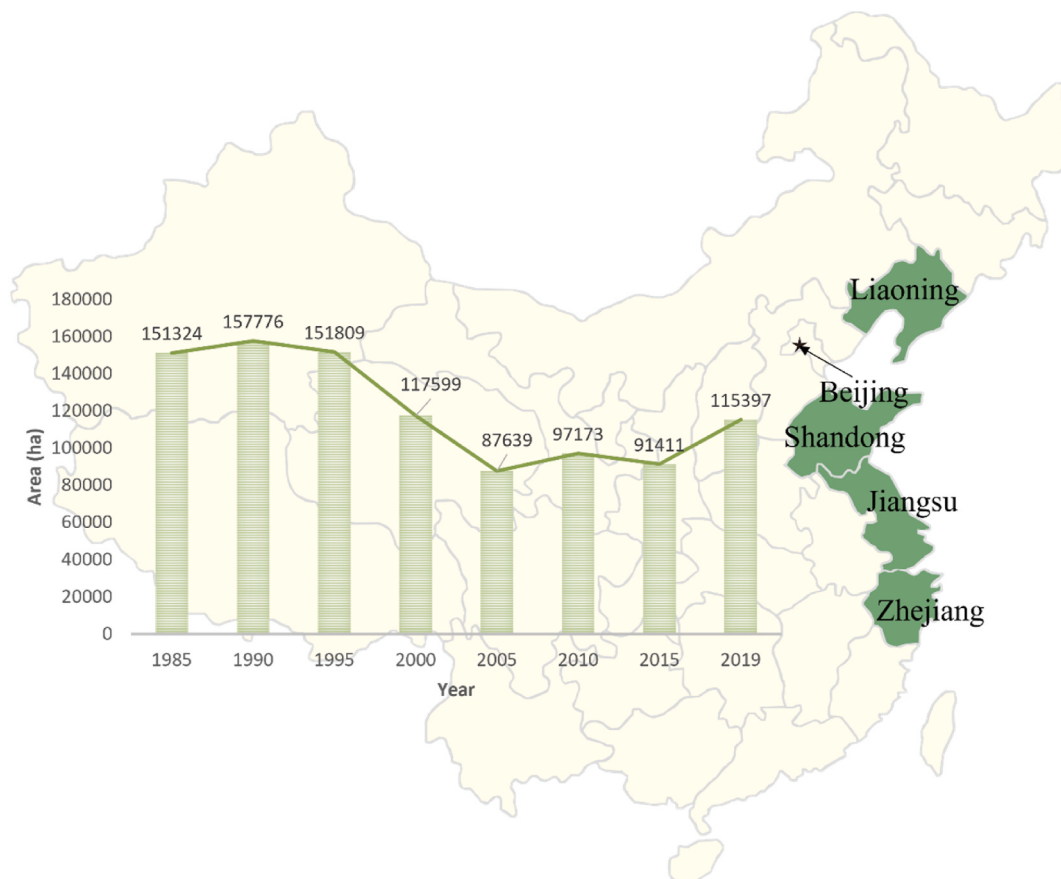


Fig. 2. The primary distribution and year-by-year occupation area of mangroves in China. Adapted from Chen et al. (2022a).



Fig. 3. The primary distribution areas of seagrass in China. Adapted from Li et al. (2022a), Xiao et al. (2020) and Zhou et al. (2023).

mindset of scarifying environment to develop economy and over the last 20 years, continuous efforts have been taken by various parties, but have yet to reach their pre-damaged levels. There are still insufficient protective measures for these three (mangrove, salt marsh and seagrass) CBC ecosystems, necessitating accelerated legislation and enhanced enforcement efforts to prevent violations and the recurrence of damaging incidents. Although mariculture is widely distributed in China (Fig. S2), its carbon sequestration capacity remains controversial due to the short cultivation period as well as potential carbon emission during culture, harvesting and transportation of product (Guan et al., 2023; Pernet et al., 2024; Zhang et al., 2017).

3. BC policy framework evaluation

In order to mitigate and even reverse the significant loss of biodiversity and BC ecosystem itself, promoting legislation within the national policy framework and increasing government support is a crucial solution (Herr et al., 2016; Li and Miao, 2022).

3.1. BC legal conditions

Regarding the BC legal conditions, China currently has two relevant laws at the national level, namely the Marine Environmental Protection Law of the People's Republic of China and the Island Protection Law of the People's Republic of China (Marine Environmental Protection Law of the People's Republic of China, 2023; Island Protection Law of the People's Republic of China, 2009; Zhu and Li, 2022). Both laws explicitly state that the State Council (Central People's Government) and coastal local governments at all levels must take measures to protect marine ecosystems, including mangroves and seagrass. But neither of them mentioned the importance of protecting salt marshes which is a

shortage.

Besides, the laws primarily address the protection of coastal ecosystems with scientific and economic value without explicit provisions regarding the protection of ecological benefits such as carbon sequestration. Additionally, there is a lack of clear specifications for law enforcement agencies, leading to inadequate supervision and rectification efforts (Marine Environmental Protection Law of the People's Republic of China, 2023; Island Protection Law of the People's Republic of China, 2009). As a result, this has led to the negative environmental incidents, such as the destruction of mangroves in Hainan back in 2023 (Ministry of Ecology and Environment of the People's Republic of China, 2023).

To strengthen the protection of BC, both national and regional authorities must enact specialised legislation, providing effective legal foundations for the management of BC. Additionally, it is crucial to establish dedicated institutions for BC management to prevent the recurrence of activities that could harm BC.

3.2. BC policy conditions

In terms of BC policy conditions, there is "The Twelfth Five-year Plan" at the national level for developing the national marine industry in China (National Development and Reform Commission Ministry of Land and Resources & State Oceanic Administration, 2012). At the regional level, various development plans exist, such as the BC Economic Development Action Plan (2021–2025) released by the Weihai Municipal People's Government and the "Twelfth Five-year Plan" for the development of marine economy in Guangdong Province (Weihai Municipal People's Government, 2019; Guangdong Provincial People's Government, 2012).

These documents outline the action goals and priorities at both the

national and regional levels in China, specifying the implementation of ocean carbon sequestration initiatives, the establishment of wetland parks, the construction of marine ranches, and the utilization of the carbon sequestration function of fisheries, among other measures. Moreover, the regional policies complement national policy guidelines, working in tandem to support sustainable coastal management.

Taking regional policies as an example, Rushan City in Shandong Province released the Rushan BC Economy Development Action Plan (2022–2025) in 2022, in alignment with national and provincial development plans (Rushan Municipal People's Government, 2022). The document states that by the end of 2025, a BC economic system should be largely established, with the marine economy accounting for over 30 % of the city's total economy. Specifically, the plan calls for the establishment of a locally adapted BC system in collaboration with local universities, research institutes, and enterprises. Additionally, it proposes the creation of a marine ecological environment monitoring platform and a marine carbon sink trading platform to promote ecological protection and the development of the BC economy. Furthermore, the plan includes the construction of production bases, such as deep-sea seedling and breeding bases, a fine breeding base for spotted halibut, and a marine shellfish seed industry cultivation base (Rushan Municipal People's Government, 2022). These concrete measures reflect the alignment between the local Chinese government initiatives and national policies while effectively supporting local enterprises by providing policy-level assistance.

3.3. BC market and government subsidies

Concerning of BC transactions, China's relevant policies and legal framework need to be well-established (Li et al., 2022b, 2023b; Zhu and Li, 2022). There is no formally enacted specific legislation to support related BC transactions, and currently, BC has yet to be included in China's certified emission reduction programmes (Li et al., 2023a; Li and Miao, 2022; Liu et al., 2022). Therefore, the legal system related to BC market needs solemn improvement in China.

Moreover, in terms of resource property rights, issues related to the ownership, usage, benefits, transfer rights, attribution, division, and circulation of ownership rights, usage rights, and revenue rights for BC resources, carbon sinks within BC ecosystems, and other ecosystem service values remain unclear in China (Li et al., 2022b, 2023b). The institutional barriers in property rights constrain the market-oriented development of BC assets, impacting businesses' enthusiasm to participate in market activities (Chen et al., 2022b).

To summarise the BC policy framework in China, in terms of legislation, Chinese national and local governments should enact specialised laws to strengthen the protection of BC, providing an effective legal foundation for BC management. Additionally, efforts should be made to establish dedicated BC management agencies, enhancing the inspection and protection of BC resources to prevent the recurrence of activities that could harm BC in China. For the BC market policies, the Chinese government should enact specific legislation for BC transactions to promote and protect carbon trading, integrating it into China's certified emission reduction programmes. Besides, ownership and usage rights of BC resources should also be clearly defined to ensure the enthusiasm of businesses in China. Furthermore, to promote the development of China's BC industry, a strong regulatory body is essential. To prevent the depreciation of collateral caused by fluctuations in the carbon sink market or policy changes, this regulatory body should employ various technological means for assessment and coordination. The continuous monitoring and evaluation methods available to this regulatory body should be as simple and precise as possible, by integrating remote sensing, drones, and field investigations. For example, Chu et al. (2022) utilised the chlorophyll assimilation index and satellite remote sensing inversion methods. Lastly, standards on BC accounting are suggested to be more accurate and specified, additionality and baseline shall be added, which can increase the accuracy and trustability of BC

marketing.

4. CBC market and SWOT analysis

4.1. Current market product analysis

Currently, based on trading platforms, China's BC trading can be roughly categorised into BC loans, BC trading, as well as BC insurance (Fig. 4) (Chen et al., 2023; Qian, 2022).

The two parties, BC enterprise and the insurance company in the green dashed box, are mainly involved in BC insurance (Chen et al., 2023). The BC enterprise obtains coverage by ensuring it with the insurance company. If marine environment changes reduce the carbon sequestration capacity of the insured species, the BC enterprise will receive compensation based on the reduced carbon sequestration capacity (Cui and Yao, 2022; Yang and Shen, 2024). This type of BC insurance not only promotes economic development and creates job opportunities but also provides protection for industries such as aquaculture, by reducing risks in the production process. Additionally, it enhances BC sequestration, contributing to carbon neutrality and environmental protection. Moreover, the compensation provided by the insurance in the event of disasters plays a crucial role in the restoration process, by ensuring production stability.

Currently, China is in the early stages of exploring marine ecological insurance, with both the Chinese government and corporate businesses actively experimenting with the BC insurance to address changes in the marine environment and enhance BC sinks. One notable case involves the Chinese government of Fujian Province insured mangroves whose coverage not only includes typical natural disasters and accidents, but also includes responsibilities for issues such as biological invasion and pest infestations (Wang et al., 2022). This unique insurance contributes to the augmentation of BC sinks and establishes a robust risk barrier for the construction of nearshore ecosystems in China.

BC loan can be understood as a financing activity in which project developers pledge the expected future revenue of BC sinks as collateral (Liu et al., 2022; Yang and Shen, 2024). This type of carbon loan can promote the transformation of traditional fishing and marine aquaculture industries and expand the scale of carbon sink fishing and marine aquaculture industries. However, there are several limitations in this type of carbon loan, such as inadequate long-term financing, small scale, and uncontrollable risks (Liu et al., 2022; Yang and Shen, 2024).

Table 1 shows some examples of current BC loans in China; and it is found that BC loans in China have the characteristics of high diversity. Various types of BC loans are offered, providing extensive financial support to enterprises and effectively promoting environmental conservation in China. Simultaneously, BC loan providers and investment amounts range from the industrial and commercial banks of China to regional banks, with loan amounts ranging from 0.5 to 200 million CNY (0.75–30 million USD). The wide range of loan amounts reflects the diverse financing support banks provide to enterprises of different sizes, promotes financial inclusion, and meets the needs of various stakeholders, while also supporting the protection of BC ecosystems and increasing carbon sinks in China.

In the example of China's BC loans shown in Table 21, the marine carbon sink revenue pledge loan issued in 2021 is relatively representative as the first such loan in Guangxi (Tong, 2022). In this case, a total of 500,000 RMB (approximately 68,439 USD) was lent to Guangxi Xiaozhao Agricultural Technology Co., Ltd. It is estimated that from 2022 to 2024, the microalgae cultivated by the company can absorb a total of 65,580.94 tonnes of CO₂ (Department of Agriculture and Rural Affairs of Guangxi Zhuang Autonomous Region, 2022). This loan has multiple benefits, not only promoting economic growth but also enhancing BC sequestration and supporting the company's research and development of related technologies.

Similar BC loans also exist on an international scale. For instance, the International Finance Corporation (IFC) has disbursed over 1.9 billion

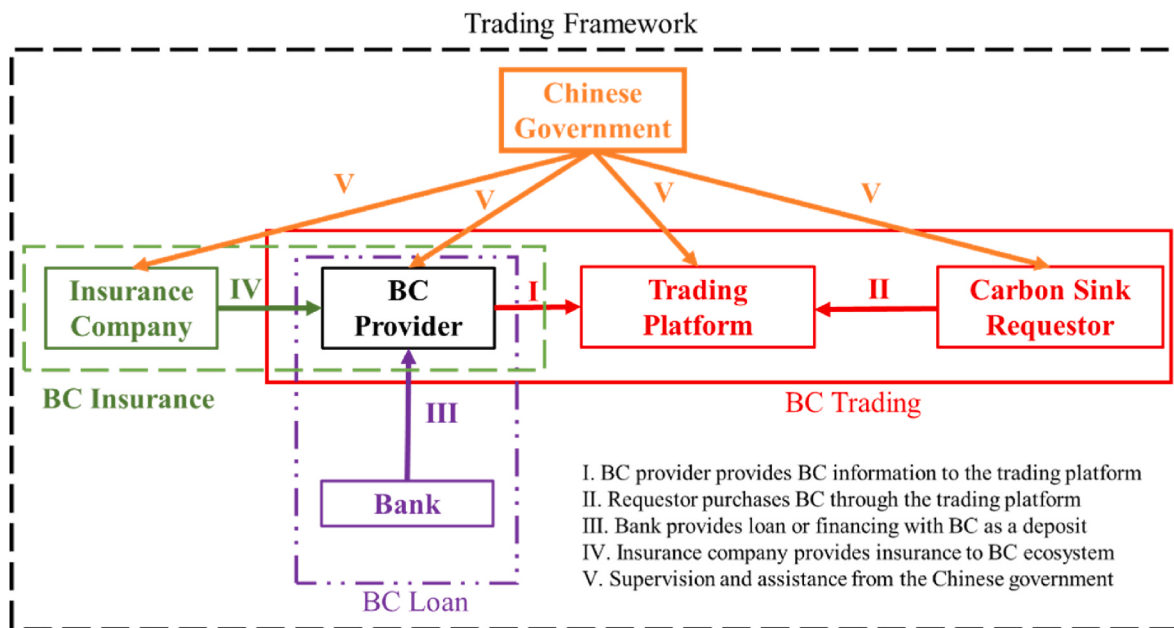


Fig. 4. General framework of BC trading in China, elements inside red boxes refers to BC trading participants, those in green box refers to BC insurance participants and purple box refers to BC loan. Adapted from Li et al. (2023a).

USD in blue loans and bonds to enterprises across various regions (International Finance Corporation, 2024). A notable example is the IFC's loan of approximately 120 million USD to Yapı Kredi Leasing, a leading Turkish leasing company, which aims to support marine and ocean related economic activities as well as initiatives to prevent water pollution. These loans not only help companies secure financing but also effectively contribute to environmental protection and the development of the blue economy (International Finance Corporation, 2022).

BC trading shown in red box is not different from the conventional carbon markets, where carbon offset suppliers and buyers engage in transactions through a trading platform. Table 1 displays some current BC trade examples in China, including direct transactions and auctions. Judging from the starting prices, BC has significant enthusiasm, with an initial bid of 183 CNY (27.45 USD) per tonne, which is 2.57 times the national carbon quota price of 66.54 CNY (9.98 USD), yet the final transaction price soared to 485 CNY (72.75 USD) per tonne which is 7 times greater than the national carbon quota price (People's Government of Guangdong Province, 2023).

In short, China's carbon market is still in its early stages, with the trading activities starting late and needing related regulations and industry standards (Tan and Quan, 2022; Li et al., 2023a). Additionally, China's carbon market focuses mostly on enterprises, overlooking other entities such as the general public.

Efforts can be made to encourage the Chinese government, corporate entities, and proactive individuals to practice carbon neutrality diligently with BC. This can be achieved by promoting the Chinese government and corporate entities' purchase BC product like mariculture from BC project, which not only help with the carbon neutrality, but also aid the poverty alleviation. Moreover, the Chinese government could consider providing rewards, such as bonuses to those who actively participated in the conservation of BC ecosystems or purchased BC aquaculture products (Wu et al., 2023).

4.2. SWOT analysis for China's BC market development

SWOT analysis, a popular tool among researchers and managers, aims to help make operational decisions based on both internal and external factors. Typically, the SWOT analysis comprises two fundamental components: (a) internal factors encompassing strengths and

weaknesses and (b) external factors encompassing opportunities and threats (Zulkernain et al., 2023). Based on the related materials, Table 32 shows the SWOT analysis for China's BC market development.

4.2.1. Strengths

China has abundant marine resources with vast maritime territories and coastal areas, providing natural conditions for the development of the BC industry. There are many BC ecosystems that exhibited high capabilities for absorbing and storing BC within China's 18,000 km coastline (Xiang et al., 2022; Zhang et al., 2021). Moreover, numerous marine nature reserves such as Zhanjiang Mangrove and Dongzhai Harbour Mangrove Nature Reserves have been established by the Chinese government for their high BC sequestration ability (Ministry of Ecology and Environment of the People's Republic of China, 2006). These crucial regions for BC development offer favourable natural conditions for BC market development in China (Wu et al., 2020).

Furthermore, with a series of management policies frequently issued, it is shown the year-by-year increasing attention from the Chinese government to BC ecosystems. For example, the "National Strategy for Climate Change Adaptation" and the "National Major Functional Area Plan" illustrated the importance of BC and BC ecosystems in China (Li and Kou, 2024; Yu and Wang, 2022). Besides, the local coastal governments in China are also actively engaging in the research and protection of BC ecosystem in response to the Chinese's central government initiatives. For instance, Xiamen has launched the country's first BC trading platform, and Weihai has implemented a BC economic development action plan (Xing and Wen, 2024). This demonstrates the Chinese government's emphasis on BC, serving as a significant strength in developing the BC market in China.

4.2.2. Weaknesses

Currently, the development of the BC market in China remains in its early stages, with a need for improvement in information and transaction facilities (Yu and Wang, 2022). Although cities like Shandong, Guangdong, and Zhejiang have launched BC pilot projects, a clear and universally recognised solution is still lacking for issues related to the development, implementation, transaction, and management of marine carbon sink projects (Xie et al., 2021). These include BC measurement, ecosystem monitoring, assessment systems, and institutional

Table 1
Examples of current BC products in China.

BC Insurance Region	Insurance Company	Species	Estimated BC Sequestration (Tonnes)	Maximum Insurance (CNY)	Descriptions	Year of Insurance Establishment	Reference
Shandong	China Life	Shellfish, oysters	255,000	1,600,000	800 acres of oyster farms. The payout can be utilised for post-disaster recovery, rescue of oyster and other production activities.	2022	Cui and Yao (2022)
Shandong	China Life	Seagrass	400,000	200,000	Covering 100 acres of seagrass. The payout can be used for post-disaster ecological protection and restoration activities for seagrass beds.	2022	Qi and Cui (2022)
Liaoning	Ping An of China	Kelp, shellfish	N.A.	400,000	Covering 13.3 acres of kelp and seaweed.	2022	Xin (2023)
Fujian	China Life	Mangrove	N.A.	18,750,000	Covering for 3750 acres of mangroves.	2022	Wang et al. (2022)
BC Loan Province	Project	Total BC Sequestration (tonne)	Institution	Investment (million CNY)	Descriptions	Year of Loan Establishment	Reference
Shandong	Tangdao Bay wetland carbon sink	720,000	Industrial Bank (China)	20	A crucial habitat for diverse species and high carbon sequestration, with significant ecological functions.	2023	Industrial Bank (n. d.)
Jiangsu	Dafeng tidal flat laver planting	361,300	Bank of Nanjing	200	Seaweed's carbon benefits as deposit, enhancing marine carbon sequestration to mitigate global warming and prevent environmental issues.	2022	Shao (2023)
Guangdong	Shellfish farming	N.A.	ICBC	0.5	Secured by the carbon sink capacity generated by 80 acres of oyster beds.	2022	Wang (2022)
Shandong	Carbon sink of kelp and other seafood farming	425,000	Rongcheng Rural Commercial Bank	20	Secured by the future benefits from the annual carbon reduction generated by cultivating seaweed and various algae and shellfish across 100,000 acres.	2021	Weihai Municipal People's Government (2021)
Guangxi	Marine microalgae culture carbon sink	21,800	Guangxi Rural Credit Cooperatives Association	0.5	Secured by the carbon sink of microalgae. Estimated 65,580.94 tonnes CO ₂ sink within 2 years, 2.77 million CNY corresponding future carbon emission quota value for next 3 years.	2021	Tong (2022)
BC Trade Province	Purchaser	Traded Carbon (tonne)	Price (CNY/tonne)	Area of Traded Ecosystem (ha)	Descriptions	Year of Trading Complete	Reference
Zhejiang	Marine microalgae culture carbon sink	246.1	106	N.A.	BC from alga <i>Enteromorpha prolifera</i> . Marking China's first auction-based blue carbon trade, with the final transaction price exceedingly twice the initial bidding price.	2023	Wang (2023)
Shenzhen	Shenzhen Blue Carbon Jiahua Technology Co., Ltd.	3874.50	485	126	BC from mangrove. Initial auction price of 183 CNY per tonne, 2.57 times of the national carbon quota price. The final transaction price is twice the initial bidding price.	2023	Shenzhen Government (2023)
Jiangsu	Tencent SSV Carbon Neutral Laboratory	1926	N.A.	107	This is the first salt marsh wetland BC trade, BC sourced from the coastal tidal wetlands within the Yancheng National Nature Reserve.	2023	Li (2023)
Guangdong	Zhejiang Yiduan Precision Machinery Co., Ltd	5880	N.A.	380	At Guangdong Zhanjiang Mangrove Nature Reserve, with VCS and CCB standards. 160,000 tonnes CO ₂ estimated reduction between 2015 and 2055.	2021	Long (2021)

Note.

CCB The Climate, Community and Biodiversity Standards.

N.A. Not applicable.

VCS The Verified Carbon Standard.

mechanisms for third-party certification, along with registration, comprehensive calculation, and both government and third-party supervision and verification ([Xie et al., 2021](#); [Yang et al., 2021](#)).

Moreover, in terms of legal protection, current Chinese laws impose penalties for damage to BC resources that fail to fully compensate for ecological losses, indicating a lack of legal accountability ([Jiang, 2019](#);

[Li and Kou, 2024](#)). The BC monitoring and accounting system also remains incomplete in China ([Cheng et al., 2023](#); [Li and Kou, 2024](#)). For example, the existing “Methods for Accounting Marine Carbon Sinks” do not fully resolve standardisation issues, hindering efforts to include fisheries carbon sinks in the China Certified Emission Reduction (CCER) and carbon trading markets ([Li and Kou, 2024](#)).

Table 2
SWOT analysis for China's BC market development.

Strengths (S)	Weaknesses (W)
S1: Vast maritime territories and coastal areas	W1: BC market still in early stage
S2: Financial and governmental support	W2: Lack of legal accountability
	W3: Incomplete monitoring and accounting system
	W4: Low public awareness of conservation
Opportunities (O)	Threats (T)
O1: Global insights and good management practices from other countries	T1: Environmental disruption
O2: Fluctuation in carbon market	T2: Lack of BC funding
	T3: Incomplete international institutional framework for BC protection

More importantly, since relying solely on government initiatives to protect BC ecosystems is inadequate, active public participation is also essential. However, public awareness of coastal habitat protection remains weak, along with insufficient legal consciousness in China (Gu et al., 2023; Han and Lu, 2022).

4.2.3. Opportunities

The global attention to BC and ecological environments has gradually increased, with various countries and organisations contributing new perspectives to China's BC development. For instance, Howard et al. (2014) provided a systematic strategy for quantitative research on CBC, which can be modified and utilised in China's BC quantitative research. Additionally, many countries, including the United States of America, Australia, Japan, the United Arab Emirates and Indonesia, among others, have established national BC plans, offering insights into China's BC development (Abu Dhabi Global Environmental Data Initiative, 2013; Brown et al., 2014; Nobutoki et al., 2019; Wu et al., 2020).

The ongoing global fluctuation in carbon market prices provides market opportunities for the demand in market transactions related to ocean carbon sinks (Xie et al., 2021; Cheng and Chen, 2021). The carbon emission price has risen due to the tightening of quotas in the European Union (EU) carbon market. Besides, the resolution passed by the EU to impose taxes based on the carbon content of imported goods will also lead to an increase in global carbon prices (Li et al., 2023c). At the same time, as China progresses towards its carbon neutrality goals, carbon emission prices will also increase. The higher carbon price will result in an increasing burden on some businesses, which in turn may enhance the willingness and demand of investment in the BC and BC products from the capitalists and Chinese government. Therefore, the increasing carbon price could indirectly promote the development of China's BC market (Xie et al., 2021).

4.2.4. Threats

Environmental disruptions, such as ocean acidification, eutrophication, and global climate warming, may adversely impact BC storage and quantification. For instance, acidification in the Yellow Sea and Bohai Sea could affect seagrass ecosystems and organisms like *Zostera marina* (eelgrass), impacting their metabolism (Sabine, 2018; Yan et al., 2023, 2024). Rising sea levels in Guangdong, Hainan, and Guangxi can erode mangroves and salt marshes, reducing BC storage by impairing photosynthetic functions (Fu et al., 2014; Li and Miao, 2022).

In addition, funding for BC ecosystem conservation has long been insufficient. The recent economic downturn, intensified by the COVID-19 pandemic and global challenges, has caused serious fiscal deficits, restricting China's investment in BC ecosystem creation and restoration (Gu et al., 2023). Meanwhile, societal groups such as businesses often perceive low returns on BC restoration projects, leading to pessimism about their viability. As a result, enthusiasm and willingness for social investment in these efforts remain low (Gu et al., 2023; Sun et al., 2023).

Furthermore, the current international institutional framework for

BC protection is incomplete. Although there are laws related to marine environmental protection, particularly covering mangroves, seagrass, and salt marshes; China still lacks a comprehensive system specifically for BC conservation. This results in weak legal safeguards and hampers the development of BC mechanisms in China (Zhu and Li, 2022). As a consequence, it also limits international cooperation, adding uncertainty to global BC conservation efforts (Li and Li, 2022).

5. BC best management practices (BMPs) in other countries

5.1. Australian CSIRO Coastal Collaboration Cluster

The CSIRO Coastal Collaboration Cluster in Australia aims to connect sciences with the needs of governments, communities and industries to meet coastal challenges (The Commonwealth Scientific and Industrial Research Organization, n.d.). Within its cluster, the report entitled "Technical Review of Opportunities for Including Blue Carbon in the Australian Government's Emissions Reduction Fund" was prepared for the Department of the Environment and Energy, and is considered as one of the most comprehensive assessments of BC ecosystems and sequestration in Australia (Kelleway et al., 2016). This report analysed the current BC ecosystems in Australia as well as the influencing factors in the BC ecosystem, which provide information for national reporting and policy development on BC development (Department of the Environment and Energy, Australian Government, 2019; Kelleway et al., 2016; Steven et al., 2019). Similarly, the Chinese government or third-party can set up a cluster to combine the BC participants together to better protect, develop and utilise the BC ecosystem. Furthermore, the Chinese government can collaborate with scientists from various disciplines to conduct a comprehensive assessment to the BC ecosystem as well as the influencing factors, which will benefit the further decision-making.

5.2. Yokohama BC project

The Yokohama BC Project, initiated in 2014, aims to address global warming by generating synergies across environmental aspects (such as water purification and biodiversity conservation), societal dimensions (such as improving convenience facilities and enhancing the Yokohama brand), and economic factors (such as increasing resources, food supply, and boosting tourism) in Japan (Nobutoki et al., 2019). Compared to current projects in China, the Yokohama BC Project integrates various entities, including individuals, civic groups, fishermen, businesses, educators, and the Japanese government (Kuwaie et al., 2022). According to Kuwaie et al. (2022), the public gave positive feedback to the Yokohama BC Project and the reason behind it may be the involvement of multiple entities which made purchaser be more sympathetic to the whole project instead of credit alone. Similarly, the Chinese government and regional authorities can connect BC with people's daily lives through diverse projects or activities rather than treating it as a stand-alone initiative since this approach can bolster public support for BC, thereby promoting carbon peaking and neutrality efforts.

5.3. Abu Dhabi BC Demonstration Project

Abu Dhabi is located at middle west of the United Arab Emirates, on a T-shape island in the Persian Gulf. The main development structure of the Abu Dhabi BC Demonstration Project is shown in Fig. 5. The project started with analysing carbon sequestered within the mangroves, seagrasses, salt marshes, algal mats, and coastal sabkhas in Abu Dhabi to form a BC map. Subsequently, the project evaluated the ecosystem value based on the BC map and local ecosystem services, which will further combine the policy and financial feasibility to form opinions on BC actions for Abu Dhabi's development (Abu Dhabi Global Environmental Data Initiative, 2013).

Additionally, it was observed that the Abu Dhabi Global Environmental Data Initiative (AGEDI) played a crucial role in addressing the

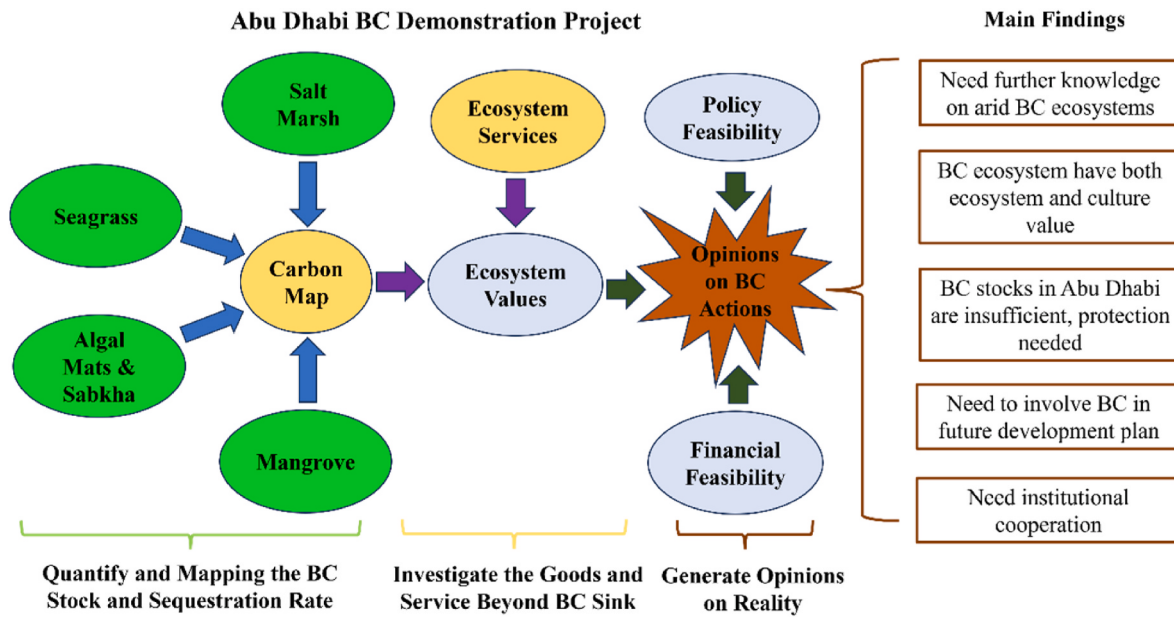


Fig. 5. The overview of Abu Dhabi BC Demonstration Project components and main findings. Adapted from Abu Dhabi Global Environmental Data Initiative (2013).

problem of lacking high-quality, quantifiable environmental data globally and especially in developing countries across the Arab world, helping them towards sustainable development. AGEDI facilitated information exchange by collaborating with the Environment Agency-Abu Dhabi (EAD) and the United Nations Environment Programme (UNEP) (Abu Dhabi Global Environmental Data Initiative, n.d.).

The Abu Dhabi BC Demonstration Project provided an optional pathway for formulating BC policies in China. Additionally, the emphasis on cooperation and data information shared by AGEDI, which was lacking in China, was highlighted. Hence, it is suggested that the Chinese government support the establishment of such platform for information exchange and collaboration to advance BC research and further promote the market development in China.

5.4. Indonesian community-based mangrove management (CBMM)

CBMM involves the local communities in the restoration and management of mangroves in Indonesia (Damastuti et al., 2022). CBMM adopts a combined approach of top-down and bottom-up methods. The bottom-up approach entails that each village forms their own local working group, who actually goes into field and working on the conservation on mangrove ecosystem in Indonesia. The working groups has the authority to devise plans based on community conditions, which are then submitted to the Indonesian government for approval. The top-down approach involves Indonesian local government and relevant departments conducting field assessments like ecological, hydrological and disturbance assessments on mangrove ecosystem, and subsequently advising the local working groups on areas for improvement and maintenance. Besides, financial support and necessary skill training are essential in the top-down routine (Brown et al., 2014).

The CBMM in Indonesia effectively reduces the management cost of mangroves and creates employment opportunities, helping local communities to break free from poverty. Additionally, CBMM efficiently utilises subjective initiative, empowering those actively engaged in mangrove ecosystem conservation to make decisions tailored to their specific circumstances. Moreover, CBMM provides ample mangrove conservation expertise to local workers, facilitating more streamlined communication between the workers and the Indonesian government (Brown et al., 2014).

Consequently, this suggests that China could divide the large-scale mangrove conservation task into smaller parts and allocate them to

township-level governments and local working groups, thus reducing the difficulty of mangrove maintenance. However, to minimise errors and ensure a more scientific approach to BC conservation in China, it is crucial to deploy experts and scholars for timely supervision of the conservation process and training of the workers.

5.5. Brief summary on BC BMPs

Table 3 summarised the significant features of the BC BMPs from other countries and what can be learnt from them. In China, there is a need to establish a communication platform like AGEDI in Abu Dhabi and to conduct a national BC survey like Abu Dhabi BC Project and CSIRO Carbon Cluster in Australia for further communication, policy making, and market development. In the BC survey and conservation process, CBMM in Indonesia involves local communities, making the process easier by fully utilising the subjective initiative of the public and society. Furthermore, BC market and government should not solely emphasise on the three (mangrove, salt marsh and seagrass) CBC ecosystems, but also consider the carbon sink in aquaculture, which will create both economic and environmental value.

6. Conclusion and future outlooks

In recent years, utilising BC to address climate changes has been a preferred option globally, while China has vast maritime territories and coastal area that provided essential condition and benefits for BC development. Hence, the current BC ecosystem status, BC policies and market demand in China as well as the BC BMPs from other countries were discussed in the present study. As a result, the following suggestions can be made.

- 1) In China, BC ecosystem protection remains essential; not only should the BC area be expanded, but also the quality needs to be highlighted. Involving the public in BC protection efforts could reduce costs and increase efficiency for coastal sustainability in China.
- 2) The Chinese government and regional authorities should establish relevant regulations, as the current protection efforts for BC ecosystems such as salt marshes remain insufficient, requiring dedicated legislation for improvement. Additionally, there is still a lack of legal frameworks and enforcement agencies for carbon sequestration protection, resulting in inadequate oversight and regulatory efforts.

Table 3
Summarisation of the BC BMPs.

Project Name	Country	Significant Features	Learning Insights for China	Year of Establishment
CSIRO Coastal Collaboration Cluster	Australia	Researches of BC on influencing factors current situation	BC resource census BC influencing factors analysis	2017
Yokohama BC Project	Japan	An organic and effective cluster Public participation in BC market Diverse BC market product	Combine science, government and market Fully utilise subjective initiative of public	2014
Abu Dhabi BC Demonstration Project	United Arab Emirates	Comprehensive assessment of BC Platform for information exchange	A possible pathway to adapt BC actions A communication platform is needed	2012
Community-Based Mangrove Management	Indonesia	Public participation in conservation	Combination of bottom-up and top-down approach	N.A.

Note.

N.A. Not applicable.

Furthermore, the BC market lacks standardised implementation guidelines and monitoring mechanisms. Standardising BC transactions can enhance market confidence, promoting both economic growth and environmental protection.

- 3) Further scientific studies on BC ecosystems are needed, including the comprehensive assessments on BC stock in China and an examination of the influencing factors of BC sink in each (mangrove, salt marsh, and seagrass) ecosystem. Besides, an effective communication and cooperation platform is necessary to connect all relevant BC stakeholders with the government in China's BC market.

However, due to force majeure, the analysis of China's current BC ecosystem is not comprehensive enough, and additional comparisons and case studies on BC best management practices can be included and analysed in future studies.

In a nutshell, the status of BC in the international community is gradually increasing, and China's BC resources are relatively abundant, providing unique advantages. China can fully utilise this advantage, coupled with its advanced technology, to collaborate closely with other countries for both regional and global BC developments.

CRediT authorship contribution statement

Tianze Gu: Writing – original draft, Visualization, Investigation, Conceptualization. **Chuck Chuan Ng:** Writing – review & editing, Validation, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ocecoaman.2025.107699>.

Data availability

No data was used for the research described in the article.

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